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Multicast and Broadcast Enablers for High-Performing Cellular V2X Systems

Mikael Fallgren, Taimoor Abbas, Sylvain Allio, Jesus Alonso-Zarate, Gábor Fodor, Laurent Gallo, Apostolos Kousaridas, Yilin Li, Zexian Li, Zhongfeng Li, Jian Luo, Toktam Mahmoodi, Tommy Svensson, Guillaume Vivier*

***Abstract*— This paper focuses on capabilities enabled by 5G connectivity in the cooperative, connected and autonomous cars, and elaborates on two technical enablers. One of the technical enablers consists of a beamformed broadcast/multicast technology that builds on adaptive and robust beam management techniques at the air interface. The other proposed technical component aims to improve the end-to-end architectural design of 5G networks to enable efficient broadcast and multicast transmissions for vehicle-to-anything services. Finally, the key results of multicast and broadcast technical components are described and ongoing and future areas of work and research are detailed.**

Index Terms—5GCAR, Beamforming, End-to-End Architecture, V2X

I. Introduction

THE future generation of wireless communication networks, 5G networks, will enable a number of unprecedented use cases and define many business opportunities. The improved capacity, reliability, massive concurrent access, and ultra-low delay compared to previous generations, will boost the potential of the internet of things (IoT), connecting billions of devices all over the world to the Internet and enabling the remote action-reaction between remote locations with extremely high accuracy and low latency thus enabling mission-critical operations. Such improved and reliable connectivity will also realize the vision of connecting all vehicles to the internet. Indeed, the internet of vehicles, where all vehicles can be connected to each other, connected to the Internet, connected to cellular network, where great computing capacities can be available, and connected with the surroundings objects, such as road-side infrastructure, pedestrians and so forth, will become a reality thanks to 5G technologies.

Partially due to all the progress being made in both the computing and communication industries, the automotive industry is on a path where vehicles are becoming continuously more aware of their surroundings than before due to the use of various types of integrated on-board sensors, including video cameras in real time, radars, light detection and ranging (LIDAR), and enabling the integration of augmented driver assistance systems in a new generation of vehicles. Consequently, the significance and reliance on capable communication systems for vehicle-to-anything (V2X) communication is becoming a key asset that will enhance the performance of automated driving and increase further road traffic safety with a combination of sensor-based technologies. Fig. 1 shows some of the different technological components that must be ready and commercially available once the concept of connected, cooperative, and autonomous vehicles is set out in public streets. As the figure shows, V2X technologies for traffic management, automated driving, or teleoperated support need to be built on top of a number of key technology components. These include software-Defined and Virtualized 5G V2X slices, trustful security and privacy mechanisms, efficient mobility management as vehicles move around and change their point of attachment to communication networks, reliable multi-antenna diversity techniques, both network-assisted and non-assisted V2X links for fast data exchange among vehicles, mechanisms to ensure the coexistence of various radio-interfaces, efficient group-management transmission schemes for both multicast and broadcast of information, accurate positioning systems, and an overall efficient radio resource management strategy.

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M. Fallgren is with Ericsson Research, Sweden, (e-mail: mikael.fallgren@ericsson.com).

*The remaining authors are sorted in alphabetical order.

T. Abbas is with Volvo Car Corporation, Sweden (e-mail: taimoor.abbas@volvocars.com).

S. Allio and L. Gallo are with Orange, France, (email: sylvain.allio@orange.com, laurent.gallo@orange.com).

J. Alonso-Zarate is with CTTC/CERCA, Spain, (e-mail: jesus.alonso@cttc.es).

G. Fodor is with Ericsson Research, Sweden and KTH Royal Institute of Technology, Sweden, (e-mail: gabor.fodor@ericsson.com, gaborf@kth.se).

A. Kousaridas, Y. Li, Z. Li, J. Luo and are with Huawei, Germany, (e-mail: yilin.li@huawei.com, lizhongfeng@huawei.com, jianluo@huawei.com, apostolos.kousaridas@huawei.com).

Z. Li is with Nokia Bell Labs, Finland, (e-mail: zexian.li@nokia-bell-labs.com).

T. Mahmoodi is with King's College London, UK, (e-mail: toktam.mahmoodi@kcl.ac.uk).

T. Svensson is with Chalmers University of Technology, (e-mail: tommy.svensson@chalmers.se).

G. Vivier is with Sequans Communications, France, (e-mail: gvivier@sequans.com).

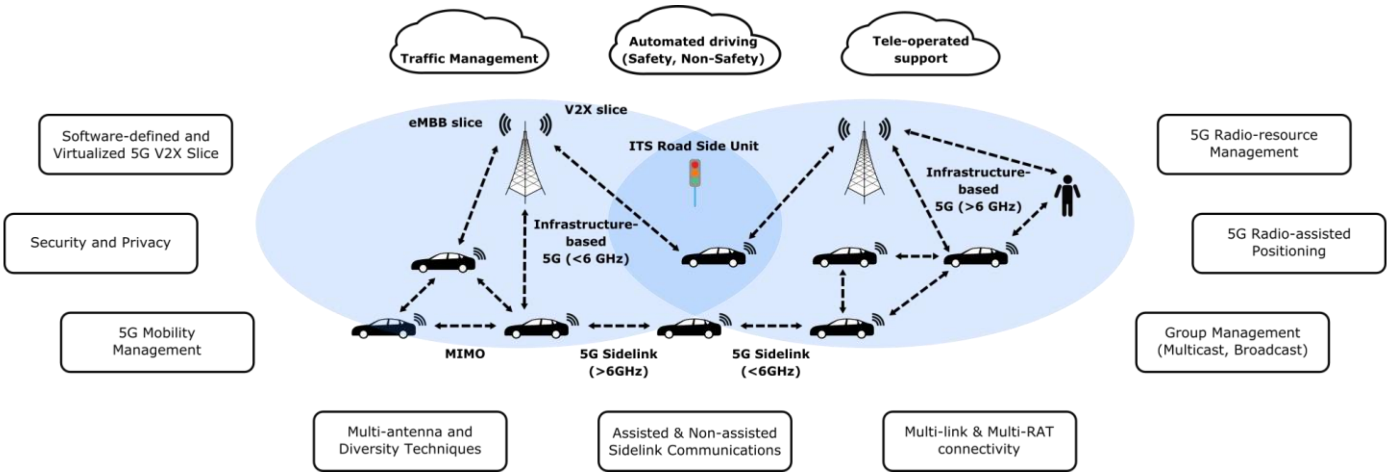

Fig. 1. The V2X concept and its key technical components.

This paper is motivated by the joint vision of the telecommunication and automotive industries of creating an efficient, sustainable and safe transportation system.

The activity of 5GCAR [1] is mainly focused on the design of innovative 5G technologies to enable V2X services, including techniques for efficient broadcasting through 5G networks. The general objectives of connected autonomous driving is to improve wireless V2X communication technologies, i.e. to reduce end-to-end (E2E) latency, improve reliability, ensure very high availability, guarantee interoperability of heterogeneous radio technologies, increase scalability (massive access), and secure vehicular communications.

The objective of this paper, however, is to introduce key technology components that have been thoroughly studied within 5GCAR and that are also being put forward for future releases of 3GPP, to guarantee efficient broadcast transmissions in 5G for V2X. Indeed, V2X solutions are being continuously improved in the context of 3GPP [2]. While the long term evolution (LTE) based solutions for V2X communication were addressed in the context of Rel. 14 and Rel. 15, the New Radio (NR)-based solutions are specified in Rel. 16 [3].

The contributions presented in this paper include both solutions regarding radio interface design to meet the stringent need for latency, reliability, data rate, and spectral efficiency at the last mile of V2X communication, as well as the E2E network design to ensure that latency, reliability and data rate as achieved over the radio interface is maintained over the E2E communications. The stringent requirements, mentioned above, are derived based on five main classes of V2X use cases [4].

The remainder of the paper is organized as follows. Section II describes 3GPP broadcast and multicast for V2X status. Section III introduces the system model. Section IV describes the main challenges of the radio interface solutions for broadcasting in V2X technologies, including quantitative results. In its turn, Section V introduces system-level architecture concepts for broadcasting in V2X. Section VI concludes the paper with final remarks.

II. 3GPP Status on Broadcast/Multicast for V2X

Broadcast/multicast mechanisms are inherent to cellular systems: in each cell, system information, synchronization channels, pilots, etc. are broadcasted to all users to support the system operation. In addition, some services are broadcasted. This is typically the case of earthquake and tsunami warning systems which alerts all users in a given area of an emergency event. Since 3G, specific mobile broadcast/multicast services (MBMS) have also been specified. This latter service requires a specific type of deployment (single frequency network) and have been simplified thanks to the introduction of single cell point to multipoint (SCPTM) [5]. SCPTM consists of supporting the MBMS services over a single cell. In addition, MBMS has been improved with the possibility of dynamically adapting the broadcast/multicast area according to the number of users who are consuming the service. In context of continuous improvement of LTE (4G) and definition of New Radio (5G), there are currently activities in 3GPP related to broadcast / multicast, such as the Release 16 study on LTE-based 5G terrestrial broadcast [6], a study on the use of MBMS services for IoT [7], etc. Those studies address architecture, middleware or radio access network aspects to further improve the support of MBMS by 3GPP solutions.

The downlink transport mode based on multicast and broadcast significantly improves the resource efficiency of the V2I and V2N links compared to that of unicast distribution. Relying on the broadcasting capability, the common data of interest can be transmitted only once to the concerned vehicles instead of addressing every vehicle separately by sending the same message over multiple dedicated radio channels. The multicast/broadcast transmission mode thus enhances the downlink capacity in the context of downlink re-distribution of cooperative awareness messages and decentralized environmental notification messages which are characterized by modest packet sizes [8]. Even higher gains can be expected in scenarios where vehicles receive high data rate V2I transmissions supporting applications such as high definition map acquisition and infotainment services requiring Gbps transmission rates [9].

The existing broadcast capability of cellular systems combined with point-to-point communications easily support intelligent transportation system (ITS) services such as road work alerts, hazard notifications and traffic alerts [10], [11]. The possibility to dynamically adapt the cell area on which the alerts or information can be broadcasted is of key interest to adapt the information content to the area for localized alerts, such as localized weather events [12].

The cellular ecosystem also considers the concept of broadcast by defining the notion of sidelink. Indeed, the original foundation of the V2X sidelink relies on the work undertaken in the context of proximity services and the definition of device-to-device communications. This device-to-device interface simply consists of broadcasting a message from a device to all devices in its vicinity.

As a result, improvements of broadcast/multicast adapted for 5G radio interface are part of the on-going study item dedicated to sidelink design for V2X which is expected to be completed in March 2019 [3]. These improvements include physical and medium access control support for both broadcast and multicast transmissions, resource pool management for unicast, multicast and broadcast services, increased support for QoS management, and enhanced reliability by employing retransmissions for broadcast and multicast sessions, as detailed in [9] and [13]. Furthermore, the innovation described later in Section IV is a typical example of a technology candidate leveraging a cellular toolbox that will evolve in the upcoming releases of the 3GPP specifications.

III. SYSTEM DESIGN AND CONSIDERATIONS

The E2E network design in this paper is built on the current developments in 3GPP based on the assumption that the network can implement network function virtualization, network slicing, and edge cloud. The radio-interface is similarly built upon a 3GPP set of solutions, encompassing unicast and broadcast links. These can be established both on the so called Uu interface, connecting the user equipment (UE) to Base Station (BS), and on the proximity service direct communication interface 5 (PC5) interface, also known as sidelink, directly connecting UEs to each other, and to UE-type road side units (RSU). 5GCAR has also proposed a number of improvements for multicast and broadcast services, which are presented in this paper. Hence, efforts have been made to design how best these technologies can be exploited to deliver the performance required by the autonomous driving services [14]. To this end, we identify the general technical challenges brought by connected autonomous driving in five main technical areas:

1) V2X main characteristics (mobility, simultaneous requirements for massive number of ultra-reliable, low latency, high bandwidth communications);
2) Multiple access network connectivity (including the management of multiple network slices);
3) Resilience requirements;
4) Security and data privacy; and
5) Roaming between operators.

Most of these challenges need to be addressed considering a wide coverage area that provides service to the extensive road network. This includes improving and enhancing the coverage of current cellular networks, which is already being handled by regular work in standardization organizations such as 3GPP and continues extensions of road coverage. This paper also investigates technical solutions that are based on short-range technologies and the use of RSUs, understanding that these types of solutions might be economically feasible in certain urban areas.

The overall system design is based on the following considerations:

Dynamic use of multi-radio access technology (RAT) and multi-links: the design in 5GCAR considers the use of multi-link radio interface, which is, using both sidelink-based and network-based communications, including the possibility of switching between them dynamically when and where needed. Integrating sidelink-based and network-based solutions utilizes advanced context information for making choices from multi-link and multi-RATs to support the required key performance indicators.

Smart zoning: Most of the V2X service data flows related to road safety and road efficiency are local or specific to individual roads that are originated or terminated by road users on the same road or even a particular area of the road. If a number of RSUs are deployed along the road, they could potentially shape a zone together to support V2X services throughout the service area while a vehicle is moving between the coverage areas of various RSUs. The smart zone concept addresses network integration and deployment arrangement, network access and admission control as well as mobility for enabling fast, reliable, and efficient vehicle communications in various mobility environments and road traffic conditions. From a conceptual view, a smart zone can be considered as a flexible and dynamically reconfigurable V2X service coverage that is local to a specific road or a limited area of the road.

Use of advanced context information: Advanced context information such as location/position, speed of vehicles, type of cooperative driving or safety application that triggers communication at the vehicle, as well as information regarding detailed network capabilities, could be exploited for further improvement of V2X communications. For example, location-aware scheduling could assign or adjust quality of service (QoS) provisioning for each single packet based on position-related information. Context-aware selection of multi-link/multi-RAT can ensure complete delivery of a cooperative driving or safety application that has been initiated from any vehicle. Finally, service negotiation will ensure that only cooperative driving or safety applications that can be completed successfully will be initialized.

Support of multi-operator: V2X communications need to be addressed in a multi-operator environment. There are several use cases where this multi-operator consideration is relevant, for example, cross-border situations when a vehicle is traversing the border between two countries, or the sidelink communication being established between two vehicles that are subscribed to different mobile networks operators. While sharing of infrastructure has been widely discussed in the literature, [15], it requires complex agreements between operators. Splitting the overall area in regions where only one operator can be active simplifies the multi-operator environment and enables efficient V2X communications [16]. Unfortunately, such a setup involves agreements between operators, including agreements on areas, where UEs are allowed to use other operator networks facilitating national roaming. Furthermore, such a setup might have implications regarding free competition laws by excluding some operators. 5GCAR has investigated various options with respect to the valid business models in [17].

Security and privacy: V2X messages exchanged over the air may trigger safety (or not safety) actions on receiving vehicles, including actions initiated by the driver when notified of some alerts or triggered automatically by autonomous vehicles. The consequences of such actions can be far-reaching. Therefore, it is critical to ensure the authentication of the V2X message sender, its permissions for sending such a message with such content, and the relevance of the message. Two possible solutions are (1) to provide E2E security, where all verifications are performed by the receiving UE, and (2) network-side-based security, where all consistency and relevance checks against a V2X message are performed by the network. The current security solutions for direct communication are handled on the application layer and are based on the idea that the authenticity of a message is ensured by signing each message using an anonymous certificate. In this solution, vehicles sign each message using a certificate randomly chosen from a pool of hundreds of available ones, which should be renewed every week. This creates challenges on the underlying public key infrastructure considering the scale of the solution with millions of vehicles performing this certificate handling, these types of solutions might be economically unfeasible in certain urban areas.

IV. Radio Interface Solutions for Broadcasting in V2X

A. Requirements and Challenges for the Radio Interface

Several V2X applications require delivering a common message to a set of vehicles over the vehicle-to-infrastructure (V2I) communication link. Among the different advanced V2X use cases identified in 5GCAR, these include the network assisted vulnerable pedestrian protection use case and the high definition local map acquisition use case falling under the use case classes of cooperative safety and autonomous navigation, respectively. Supporting unicast, multicast and broadcast communications between vehicles, vulnerable road users and infrastructure nodes in a spectral and energy efficient manner in the broad spectrum of 5GCAR use case classes imposes challenges on the radio interface. For example, adaptive and robust beam management for vehicle-to-network (V2N) and V2I broadcast and multicast services require a fast and accurate transmit and receive beam alignment, which is problematic, especially in mmWave bands [18]. Similarly, increasing the reliability of sidelink unicast, multicast and broadcast communications is challenging due to the short coherence time of the radio channel and the difficulty in acquiring channel state information at the transmitting UEs [19].

B. Radio Interface Design Based on Cellular and Sidelink Communications

To meet 5G V2X requirements, including the requirements on E2E latencies (below 5 ms), ultra-high reliability (99.999%), high density of connected vehicles and high positioning accuracy (down to 5 cm), the 5GCAR radio interface design involves a rich set of technology components that can be combined and deployed jointly such that these requirements can be met. Specifically, the 5GCAR radio interface design includes ten infrastructure-based and nine sidelink-based technology components that can be deployed in various combinations to facilitate the 5GCAR use case classes [20]. In addition, five technology components are specifically designed to enable accurate positioning and to support the various services built around such underlying positioning services.

In the next section, we focus on the technology components particularly aimed to enable broadcast and multicast V2X communications.

C. Beamformed Broadcast/Multicast Design

To facilitate broadcasting and multicasting specifically in V2X scenarios, we have developed a beamformed broadcast/multicast technology which builds on adaptive and robust beam management techniques [21], [22]. This technology is especially suitable for mmWave bands, where large antenna arrays are deployed at gNBs (5G NR base stations) and RSUs. It builds upon the SCPTM transmission scheme and employs an algorithm to coordinate the beam-domain broadcast message delivery across V2N/I links utilizing the geographical information which can be delivered via, e.g., a location server. The location server is a centralized entity able to compute and book-keep different vehicular user equipment (V-UE) awareness range groups. Specifically, the location server keeps track of V-UEs in different relevance areas by utilizing V-UEs' geographical locations [20]. This technology is described in further detail and exemplified as follows.

A single cell communication system is considered, in which an infrastructure node such as a gNB or RSU, (commonly referred to as a transmission/reception point, TRP) provides reliable multicast transmission to UEs within the cell coverage. The key idea is to exploit the fact that UEs that are geographically close to each other can be served by the same beam which contains common messages for such UEs. Furthermore, the TRP exploits feedback from UE acknowledgment or negative acknowledgment (ACK/NACK) feedback messages which have been designed to trigger retransmissions for enhancing the reliability of the broadcasting service. The proposed beam-scanning beamformed multicast (BSBM) transmission technology consists of the following control plane and signaling support:

- Signaling design for initial transmission
- Signaling design for hybrid automatic repeat request (HARQ) feedback
- Signaling design for retransmission

For initial transmission, we implement a novel physical channel, called the physical broadcast multicast channel (PBMCH) that is designed for data transmission only, as

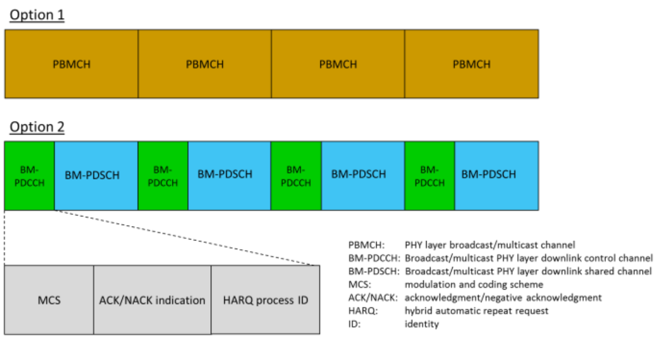

Fig. 2. Illustration of the 5GCAR PBMCH for initial transmission.

illustrated in option 1 of Fig. 2. The associated control signaling is supported by existing physical channels such as the physical broadcast channel carrying system information blocks defined in legacy cellular systems [23]. Additionally, the radio interface includes another frame structure in which control signaling and data transmission are incorporated in the multicast/broadcast physical layer downlink control channel and the broadcast/multicast physical layer downlink shared channel, as illustrated in option 2 of Fig. 2.

An inherent part of the BSBM scheme is the design of the beam-scan mechanism, which is essential to obtain initial transmit-receive beam alignment [24]. To this end, the design of the initial BSBM transmissions follows the conclusions in [25], according to which the selection of the beam scan scheme should depend on the targeted performance metric. Specifically, *single beam exhaustive scan* was found to be optimal in terms of the initial transmission latency. By contrast, *multiple beam simultaneous scan* achieves the lowest overhead defined as the portion of resources allocated for initial transmission out of all resources available in the cell.

The necessary downlink control information associated with the PBMCH transmission allows the receiving UEs to decode the PBMCH messages. This control information consists of information regarding the applied modulation and coding scheme (MCS), as well ACK/NACK indication. The resources for these pieces of information are either pre-allocated or allocated using the standardized physical downlink control channel (PDCCH). In this way, the overhead of the initial transmission is reduced.

For HARQ feedback, different timing indications of ACK/NACK feedback are supported. Specifically, the HARQ feedback can be sent either immediately after each of the beams

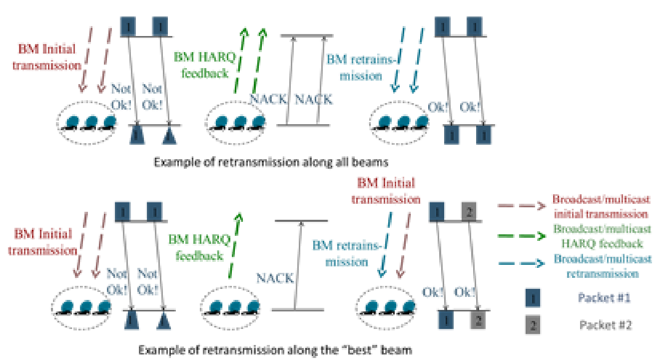

Fig. 3. Illustration of HARQ feedback and retransmission.

TABLE 1
SIMULATION SETUP FOR BEAMFORMED BROADCAST/MULTICAST DESIGN

Parameter	Value
Carrier frequency	30 GHz
Bandwidth	200 MHz
Maximum transmit power	43 dBm
Noise figure	7 dB
Subframe length	1 ms
Number of OFDM symbols	14

that cover the entire cell area, or after all beams have scanned their corresponding distinct coverage areas. In addition, since geographically close UEs belong to a single group, these UEs may receive signals from adjacent scanning beams, on which different levels of received signal power may be experienced. To improve the spatial reuse gain, UEs belonging to the same group are enabled to combine signals either from all beams they received signals from, or on the single beam with the highest receive power (the “best” beam). The selection of the “best” beam can be realized, for example, by linking to the synchronization of the “best” beam from the received synchronization signal block or the received channel station information reference signals utilizing channel reciprocity.

Finally, for retransmissions, a similar beam selection scheme can be utilized, as illustrated in Fig. 3. Specially, the packets on retransmission links are identical within each beam or group of beams, if HARQ feedbacks are transmitted along all beam directions. Alternatively, if HARQ feedbacks are transmitted only along the “best” beam, the packets on the retransmission links are specific to each beam/group and supported by beam/group-specific PDCCH indications. Fig. 3 illustrates the HARQ feedback and retransmission design of the proposed BSBM transmissions.

D. Performance Analysis

In this subsection, we compare the performance of the proposed BSBM scheme with two benchmark schemes, namely broadcast schemes in LTE-V2X [26] (without beamforming and retransmission, *LTE-V*) and LTE-V2X with retransmission (without beamforming, *LTE-V+HARQ*), in terms of achievable data rate and latency. For the sake of this comparison, we plot the achievable data rate and latency for different broadcast/multicast schemes versus different signal-to-noise ratio (SNR). The values on the *x*-axis indicate the SNR for initial transmission, and if it fails, lower SNRs are expected for retransmission(s) until the transmitted information is successfully delivered. The simulation parameters, which are in line with [27], are summarized in Table 1.

In the simulator, there are maximally 16 beams (minimum beamwidth equals to 22.5 degrees) that can be simultaneously exploited to cover the entire angular space. The possible number of simultaneous beams are the divisors of 16 (1, 2, 4, 8, or 16). Further, simultaneous transmissions to different groups of vehicles along different beams are supported at the TRP. More details of the simulation setup, including the network layout, channel model, and TRP antenna configurations, etc., are in line with those in [1]. The simulation samples are averaged over 1000 independent snapshots.

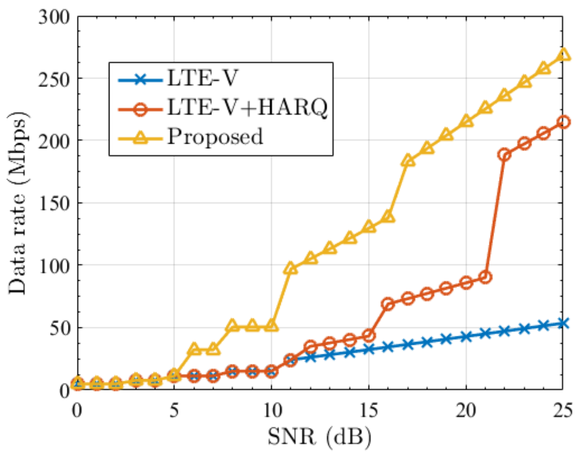

Fig. 4. Performance of different broadcast/multicast schemes for different SNR values are compared in terms achievable data rate.

The results in Fig. 4 show that the proposed scheme outperforms the benchmark broadcast/multicast schemes in terms of achievable data rate, thanks to the redundant copies of data received on adjacent beams by each UE. Receiving redundant copies enable the usage of high-order MCS that improves the achievable data rate. In particular, a small performance gain of the proposed scheme as compared with LTE-V and LTE-V+HARQ is observed in the low SNR range. The main reason behind this behavior lies in the fact that low SNR leads to retransmission failures where a conservative MCS is applied in all schemes. This, in turn, implies that the proposed scheme benefits less from the capability of using high-order MCS in the low SNR range. By contrast, the proposed BSBM scheme achieves significantly higher data rates in the medium and high SNR ranges. This gain achieved by the proposed BSBM method comes at the cost of a moderate complexity increase as compared with the LTE-V and LTE-V+HARQ schemes. This complexity increase is due to computing the beamforming weights that are inherent in the BSBM scheme.

In Fig. 5 the performance of different broadcast/multicast schemes are compared in terms of latency. As can be observed from the figure, the proposed scheme achieves the lowest latency, owing to the redundant copies received on adjacent beams. Note that at some SNR values (especially in the low SNR range), the corresponding latency value is infinite, which means that the transmitted information cannot be successfully decoded by the receiver within the maximum number of retransmissions (set as 5, and for LTE-V there is no retransmission), and therefore not plotted in the figure.

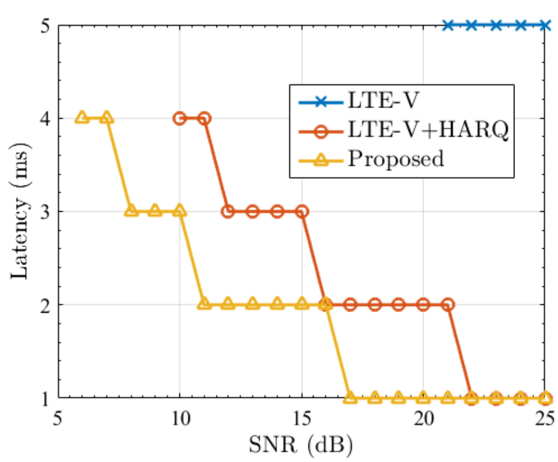

Fig. 5. Performance of different broadcast/multicast schemes for different SNR values are compared in terms of the latency.

V. System Level Architecture for Broadcasting in V2X

Yet another aspect of the 5G V2X communications is the E2E system architecture that can deliver the required key performance indicators for connected autonomous driving. Such network architecture should provide optimized E2E network connectivity for highly reliable and ultra-low latency services, enabling cooperative driving and safety scenarios, and providing the security and privacy required by the automotive industry.

A. Evolution of Infrastructure-based communication for localized Broadcast and Multicast V2X traffic

In many V2X use cases (e.g., cooperative maneuvers, sensor information sharing, video sharing) the data traffic that is exchanged among vehicles (V2V) has localized significance. This means that the communicating vehicles that participate in the same use case are located in the same geographical region and there is no need to access a remote server, (e.g., V2X Application Server, ITS cloud server), while multiple transmission modes (unicast, broadcast, multicast) might be required.

For localized V2X communications, either the cellular (Uu) interface or the sidelink (PC5) interface could be used considering the radio conditions and the environment where the V2V use case takes place. Specifically, the NR-Uu interface could provide guaranteed QoS (i.e., high reliability, low latency) especially in the case of, e.g., no line-of-sight among communicating vehicles, poor PC5 radio conditions or high PC5 load due to vehicles' high density.

The existing cellular solutions only based on the Uu interface may not be suitable for supporting the challenging performance requirements that localized V2X services have, which include the need for fast and guaranteed transmission of localized data. The cellular interface has been designed considering the features and the QoS requirements of traditional services, e.g., voice, voice over Internet Protocol, video and web data services. Considering the localized nature of the V2X data traffic, the RAN and the NR-Uu interface must be redesigned to satisfy the demanding QoS requirements and to support multicast and broadcast data transmission.

The formation of local E2E radio data paths over the Uu interface is proposed to enable the fast and guaranteed transmission of localized data traffic among the involved devices, satisfying their QoS requirements and the features of the V2X services, as initially presented in [28]. The E2E term denotes that the (user plane) radio data paths are established among the involved communicating end devices (i.e., vehicles), while the "local" term denotes that the paths are established via the BSs. The nodes of the core network do not participate in the

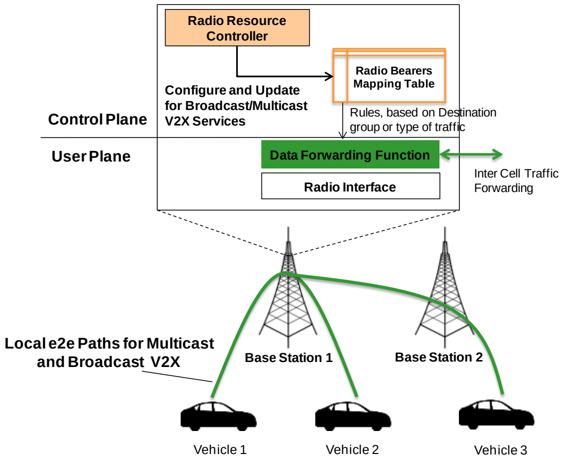

Fig. 6. Concept of fast V2V paths via the cellular interface.

user plane transmissions, since the data traffic is localized. Local V2V cellular paths via the BS can support different communication modes (unicast, multicast, broadcast) without the need to interact with other entities such as MBMS and without the need of the nodes of the core network to participate in the user plane transmissions, since the data traffic is localized. Moreover, in [29] the authors concentrate the multicast network functionalities into the layer-2 of the BSs protocol stack, but it is based on the concept of Geographical-RNTI (Geo-RNTI) that are pre-defined per area and service. New functions and schemes are added at the BS and 5G core network entities, which are presented below, to support the establishment and management of local E2E paths satisfying the QoS needs of the V2X services. Fig. 6 provides an overview of the involved entities and interfaces.

Localized communication through the Uu interface requires the introduction of a data routing/forward function at the BS (e.g., gNB) that transmits the data packets, e.g., among vehicles in a fast and guaranteed way without traversing any core network entity (i.e., user plane). This routing table in the BS maps and connects the uplink (UL) and downlink (DL) radio bearers of different UEs for the formation of the local radio paths and consequently the faster forwarding of localized V2X traffic (user plane latency reduction). According to the type of the traffic, the routing table at the BS undertakes to forward the data packet to one or more UEs in the same of neighboring cells (e.g., multicast, unicast transmissions). Data packets are also exchanged via the Xn interface (i.e., inter gNB interface) for the case that involved UEs are attached at different cells.

A UE requests the establishment (or update) of the local cellular V2V paths using radio resource control (RRC), non-access stratum (NAS) protocols, for localized V2X traffic and to transmit/receive data packets over a local E2E path. The type of the service and the identifiers of other involved UEs in the corresponding V2V service are information that the initiating UE can provide and is used for the establishment of the paths as well as for the configuration of the routing tables. RRC and NAS protocols are extended to support establishment, update and release of local cellular V2V paths between the UEs over the gNB(s) as well as to update and configure the routing table needed for the forwarding of localized data traffic. Based on these RRC or NAS messages, core access and mobility management function and session management function control the establishment, modification, and release of this new type of link (i.e., local cellular V2V paths) as well as to update and configure the routing tables that are introduced at the BSs in order to form V2V paths for localized V2X traffic over the Uu interface.

B. *Performance Analysis*

A performance analysis is provided in this section using analytical method to present the benefits of the proposed local cellular V2V path solution for user plane latency, comparing to baseline technologies for the single and multi-cell cases. The control plane latency is an also important metric for time critical services, but it is not discussed in this paper. According to the scheme presented in this paper, the core network establishes the local cellular V2V paths. Hence, we do not expect any important reduction of the control plane latency. An analysis of the control plane latency issue can be found in [28], where the option RAN-based establishment is considered.

Considering the operation of existing multicast and broadcast schemes, the overall E2E latency for the transmission of a data packet via the cellular interface, from a source to a destination vehicle is calculated as follows [30]:

$$E2E\ latency = L\text{-}RAN\_UL + L\text{-}CN + L\text{-}RAN\_DL$$

and includes the following latency components:

1) *L-RAN_UL*: the time duration from the time the vehicle has a V2X message to send over the uplink to the time the BS successfully receives the V2X message (i.e., 17.5ms+scheduling request (SR) period+(1+8*Target block error rate (BLER) %/100) in the case that dynamic scheduling with a separate buffer status report (BSR) is used [30]).
2) *L-CN*: the time duration the V2V message is travelling from the BS of the source vehicle to the BS of the destination vehicles with passing through the Broadcast Multicast Service Center, which is estimated around 20 ms [31].
3) *L-RAN_DL*: the time duration from the time BS has V2X message to send and to the time the vehicle receives the V2X message via unicast DL (4ms+8*Target BLER (%)/100, [30]).

In the case of multicast or broadcast communications, there are two baseline technologies that could be used: a) MBMS and b) SCPTM. On both cases, the *L-RAN_UL* and the *L-CN* latency components are also involved. The difference between MBMS and SCPTM lies in the time from when a V2V message arrives at the BS (of the destination vehicles) to the time when the vehicles successfully receive the V2V message. In the case of MBMS (*L-RAN_MBMS-DL*) the total latency includes the waiting time for the Multicast Traffic Channel opportunity for transmission, the DL transmission and the UE processing time. The *L-RAN_MBMS-DL* (equal to 3.5+ multicast channel (MCH) scheduling period (MSP)/2+ upper layer processing, [30]). In the case of SCPTM (*L-RAN_SCPTM-DL*) the latency depends on the SCPTM scheduling period (SSP) (equal to

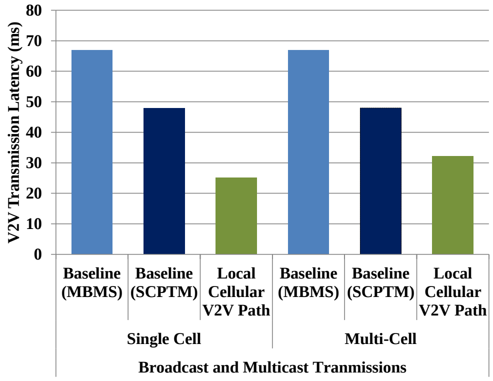

Fig. 7. Local cellular V2V path user plane latency – single and multi-cell.

2.5+*max*(SSP/2+1,2)+upper layer processing, [30]), which is shorter comparing to the MSP.

Fig. 7 presents the E2E latency for multicast and broadcast communications, comparing the baseline multicast schemes (with MSP=40ms and SSP=1ms) with the proposed local cellular V2V paths scheme. Firstly, we assume that the source and destination vehicles are located at the same BS and dynamic scheduling with a separate BSR is used (SR period=1ms and a BLER=10%). Due to the larger MSP the average E2E latency of MBMS is 67 ms, while using SCPTM the average E2E latency is 48 ms. Using the local cellular V2V radio data paths the latency that is introduced by the core network entities (e.g., MBMS Serving Gateway) is avoided and the user plane latency for the exchange of unicast V2V packets is in the order of 25ms, for the single cell case. It is better comparing to the baseline multicast schemes, showing 52% improvement comparing to the SCPTM scheme and 73% comparing to the MBMS scheme. In the case that the source and destination vehicles are located at the neighboring BSs (multi-cell case) the latency that is introduced by the inter-BS interface should be added for the communication over the local cellular V2V radio data paths (i.e., 7 ms according to [31]). However, even in this multi-cell scenario there is substantial improvement comparing to the baseline LTE-based schemes. For both cases, the improvement of the latency via the local E2E paths solution allows the realization of V2V services that more demanding in terms of latency and reliability requirements (e.g., cooperative maneuvers, sensor data exchange, cooperative perception, see-through).

VI. Conclusions

This paper has introduced the research and innovation activities that are being conducted within the EU-funded project 5GCAR. After introducing the general objectives of the project, the paper focused on the description and presentation of two key novelties that have been designed within 5GCAR to efficiently enable broadcast and multicast transmissions for V2X services.

One of these novelties refers to the air interface of 5G and consists of an improved beamformed broadcast/multicast technology that builds on adaptive and robust beam management techniques. This technology is especially suitable for mmWave bands, where large antenna arrays are deployed at gNBs (5G NR base stations) and RSUs. Numerical results show an improved performance, in terms of achievable data rate, of up to 30 percent at high SNR with regards to LTE-V2X with HARQ.

The other proposed novelty refers to the formation of local V2V radio data paths over the Uu interface to enable the fast and guaranteed transmission of localized data traffic among the involved devices, satisfying their QoS requirements and the features of the V2X services. Results show that it is possible to improve existing alternatives for the broadcast of information by more than 70 percent.

The activity of 5GCAR is planned to continue until mid-2019. Along the remaining execution time of the project, further improvements to both the air interface and E2E architecture of 5G networks will be studied and evaluated to facilitate V2X services for the connected car over 5G.

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